MONITORING THE SOUTH PEAK OF TURTLE MOUNTAIN

RESEARCH MANAGEMENT DIVISION
Alberta Environment

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This report may be cited as:

Cruden, D.M. 1982. Monitoring the south peak of Turtle Mountain. Prep. for the Research Management Division by the University of Alberta, Department of Civil Engineering. RMD Report L-77. 63 pp.

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MONITORING THE SOUTH PEAK OF TURTLE MOUNTAIN

by

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for

Research Management Division
Alberta Environment

RMD Report L-77

September 1982

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ABSTRACT

This report describes the improvement of a monitoring network installed by J. Allan in 1933 for the Alberta Department of Public Works on Turtle Mountain near the town of Blairmore in the Crowsnest Pass district of southwestern Alberta.

The network was extended in the summer of 1980 to all accessible sites at the margins of a $7 \times 10^6 yd^3$ rock wedge which may fall eastwards from the South Peak of Turtle Mountain. A network of eye bolts anchored in rock some distance from the gaping cracks is at least an order of magnitude more sensitive to movements than the previous network. Two TM 71 crack monitoring instruments can detect movements of 0.1 mm.

Further work proposed for the 1981 field season will resolve some ambiguities in the interpretation of the movements observed in 1980. Levels are set in the report for significant movements which should trigger contingency planning for a major slope failure and the installation of a remote monitoring system.

ACKNOWLEDGEMENTS

The Scientific Authority for this project, D.W. Prosser, gave valuable advice on technical matters and was a cheerful and hardworking participant in our fieldwork. The success of the project owes much to him and other members of the field parties: R. Baldwin, Dr. C. Beaty, M. Boon, Z. Chen, K. Chiste, L. Fuming, D. Fushtey, D. Gillard, B. Gudmundsdottir, O. Hungr, B. Larsen, Dr. D. McCreath, W. Milne-Home, H. Regier, and T. Sneddon. Work at Turtle Mountain is also supported by the National Sciences and Engineering Research Council and by Alberta Environment, Research Management Division.

1. HISTORY OF DISPLACEMENT MONITORING AT TURTLE MOUNTAIN

During June and July of 1933, Dr. J. Allan, under instruction from the Alberta Ministry of Public Works, carried out a survey of the cracks in the crown of the Frank Slide on Turtle Mountain. He established 18 monitoring stations (Figure 1), paint marks on either side of gaping cracks, and recommended that these stations be resurveyed at intervals (Allan 1933). The results of further surveys carried out by Allan (1938); Alberta Research Council personnel (Crockford 1948 ; Byrne 1956); Alberta Environment; and members of the Department of Civil Engineering, the University of Alberta (Krahn 1974: Table 5:1; Cruden 1977) form Table 1.

Substantial falls of rock have taken place since 1933 (Kerr 1979). None of these have crossed the Crowsnest River but the catastrophic slide from the South Peak feared by Allan (1933) remains a possibility.

1.1 INTERPRETATION OF MEASUREMENTS IN TABLE 1

Stations 15 to 18 at the northern end of the slide crown show openings in the 5 years between Allan's surveys. Byrne (1956), in the fifties, was unable to find any of Allan's stations at the North Peak. Cruden (1977) located Station 16 in 1977. Measurement showed continued dilation. Each of these stations is located on a crack running subparallel to the slide scarp. Cracks in this orientation might be expected to open if the rock between the crack and the scarp moves outwards. The thorough search conducted in 1980 revealed fallen rock at Stations 15, 16, and 18, confirming that local extension had taken place. Station 17, whose movement between 1933 and 1938 was just significant, appears to be stable.

Three other stations were located for the first time since 1938 by the Department of Environment's 1980 search. Stations 11, 12, and 13 were observed to gape at close to their 1933 values. Station 10 had shown a 20% increase in gape between 1933 and 1938 and Station 14 was the only station to show a decrease in gape in that time period.

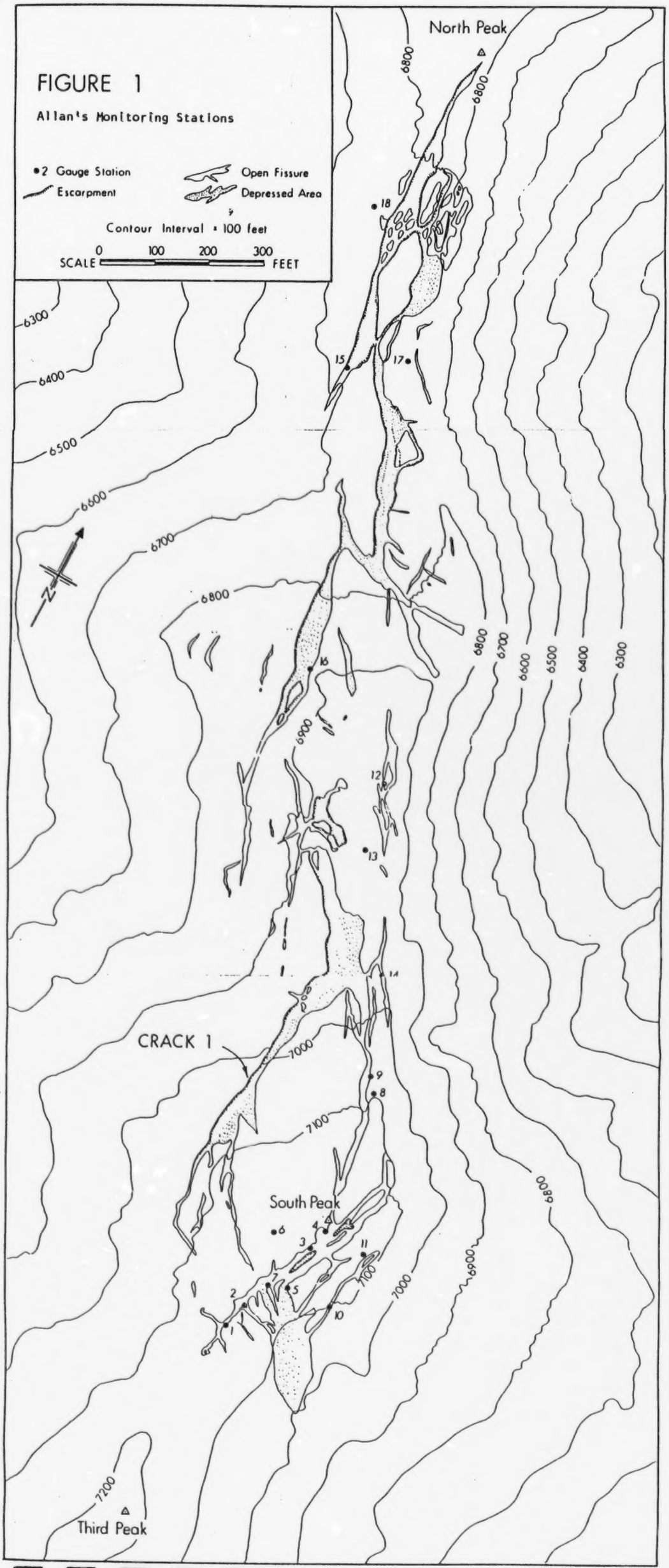
FIGURE 1
Allan's Monitoring Stations
•2 Gauge Station
Escarpment
Open Fissure
Depressed Area
Contour Interval = 100 feet
0 100 200 300
SCALE FEET
North Peak
South Peak
Third Peak
CRACK 1
6300
6400
6500
6600
6700
6800
6900
7000
7100
7200

Table 1. Gapes of cracks at Turtle Mountain.

Station	Date 7/33	7/8/34[b]	4/9/38	15/8/48	20/9/71	11/7/77	7/6/79	30/7/80	Cf 1933	Cf 1938
1	0.63	0.78	0.66	fallen				1.64		-
2	1.65	1.82	+1.69	-1.63	1.63	1.62	1.65	4.16	+	
3	4.10	4.10[c]	+4.15	-4.09	+4.20	4.19	4.17	3.34		-
4	3.35	3.40	+3.39	-3.33	3.34		ND[a]	4.19	+	-
5	4.10	4.17[c]	+4.23	-4.17	4.16	4.17	4.18	0.52		
6	0.54	0.65	0.54		0.52			+8.79	+	-
7	8.70	8.90	+8.86	-8.77			-8.58			
8	on face fallen									
9	0.65	1.02[c]	fallen							
10	0.87	1.04[c]	+1.04					-2.73		-
11	2.70	2.90	+2.80					-3.62	+	-
12	3.50	3.80	+3.71					-3.32		-
13	3.30	3.40	+3.39							
14	3.70	3.65	-3.63					fallen		
15	4.08		+4.15					fallen		
16	14.37	14.3	+14.52			+14.98		-1.63	-	-
17	1.67		+1.71					fallen		
18	0.98		+1.01							

Notes:

[a] Located but snow filled.

[b] Allan's (1933) field notes comment "not reliable omit". These measurements have not been used in computing significant changes.

[c] Some observations were included in the 1938 table of comparison in Allan's (1938) field notes. +, - indicate significant changes between successive measurements. A significant change is estimated as 0.04 ft.

Such anomalous behaviour indicates instability. Now only half of Station 10 remains and Station 14 could not be located. It has, presumably, fallen.

Station 1 to 7 are on cracks running almost perpendicular to the ridge crest. Part of Station 1 has been dislodged; the other stations show no simple pattern of movement, possibly because significant outward movements would appear as shears along the cracks rather than dilations of the cracks. For a crack open 4 ft, a shear displacement of 0.25 ft is necessary to show a detectable increase in distance between points on either side of the crack of 0.01 ft. At Stations 3 and 5, for instance, about 2.5 ft of shear movement may have taken place since 1933.

1.2 PRECISION OF THE MEASUREMENTS

Since 1971, measurements at the stations have been conveniently made with an extending steel tape. Standard deviations of repeated measurements at a station are of the order of 0.01 ft; the largest source of scatter probably arises from difficulties in exactly replicating each measurement. Allen's paint marks have diameters of 0.1 ft and are no longer easily distinguishable.

Temperature corrections of the tape or the use of a higher quality surveying tape are unlikely to produce more precise measurements if measurement end points are indistinct.

Slope movements may also be obscured by cyclic changes in crack width caused by changes in moisture and temperature of the rock mass between the cracks. As the temperature warms in the spring, ice formed in cracks within the mass may thaw causing deflation of the mass. The moisture released in melting may contribute to pore pressures within the mass, dilating it. This moisture may also be absorbed by the rock with some dilation. A rise in temperature of the mass will cause some expansion which could be noticeable if the masses between the cracks were large. Expansion due to heating would show both as a diurnal change and as a seasonal cycle as warming penetrated more

deeply into the rock mass. Similar short- and long-term cycles could be expected as water contents changed after precipitation.

The size of the changes is difficult to assess. It may be of the order of tenth of a foot, judging from differences observed between the apparently stable stations on the south side of the slide. Clearly, if precise measurements are to be made, these cyclic changes should be understood and removed. Comparison of the two most complete sets of data since 1933, those of 1938 and 1980, shows eight significant changes, all decreases, in gape in 1980. This pattern of behaviour is probably due to the 1938 observations being taken in September when gapes would be increased as the rock contracted with the seasonal decline in average temperature. Differences between the 1933 and 1980 observations, both taken in mid-summer, are less pronounced. Four of the 1980 observations indicate an increase in gape, one shows a just significant decrease in gape.

1.3 CONCLUSIONS

1. Of the 18 stations set up by Allan, only 10 remain operative. Six are known to have been destroyed by rock fall. It is likely this was also the fate of the other two stations which have not been found since 1938.
2. None of the operative stations are sited to allow the detection of extensional movements that might precede failure along the crack identified by Allan.
3. Shear movements cannot be reliably detected by measurement of crack widths which fluctuated by as much as 0.1 ft over the June to September measurement season.

2. FIELD PROGRAM: JUNE TO SEPTEMBER 1980

2.1 INTRODUCTION

Larocque (1977) recognized three levels of activity in a typical monitoring project in an open pit mine. At Level I, monitoring is designed to locate areas of potential instability. Level II involves the detailed observation of potential instabilities recognized in Level I. Level III monitors actual instabilities so that activities in the area of the instability may be safe.

With the report of Allan (1933) identifying an area of potential instability at the South Peak of Turtle Mountain, this project moved to the start of Level II activities. Larocque (1977: summary) commented, "Level II. When a potential instability is detected, the monitoring effort must be intensified. It is important to determine:

a. the area and boundaries of the unstable zone,

b. the amount and rate of movement, and

c. the general direction of motion."

Allan (1933: p. 11) identified "the major break of first rank significance"--Fissure 1--and commented: "No. 1 fissure almost encircles South Peak on the west side, and outlines a block extending from a point 300 ft south of South Peak to a point about 600 ft N 10° W of South Peak...At 7000 ft, 300 feet southeast of South Peak, there is a perpendicular cliff in which the rock is badly cracked. This represents the bottom of the unstable part of South Peak...a pyramid block of over 7 000 000 cubic yards."

The western margin of the wedge is clearly defined by a scarp, up to 5 m high, west of the South Peak (Allan 1933: Photograph 20). Southwards, the scarp dies out into a number of fissures which run eastwards into the col between South and Third Peaks. The only fissure which continues any distance down the east face beyond the col is that on which Allan's Station 2 was placed. Furthermore, this

fissure appeared deeper and cleaner than the others which ran from Fissure 1. Finally, comparison with Allan's map (1933: Plate 1) indicated that the fissure was not prominent in 1933 and hence had opened since that time. Notice, however, that Allan (1933: Photograph 14) shows the fissure with a substantial gape. It may be that the steep, bare rock slopes immediately west of the col were sufficiently difficult to map by plane--tabling that detail in this area was skimped (Allan's field notes suggest much of the plane table mapping may have been entrusted to two undergraduate engineering students).

Thus, Allan (1933) provided a hypothesis about the boundaries of the unstable zone and left the amount and rate of movement to be determined along with the general direction of motion. In the network which Allan set up himself, only Station 2 is sited to detect movement of the wedge. So the establishment of other stations round the wedge was a priority.

2.2 ACCESS

The summit of Turtle Mountain is not a safe helicopter landing site; there are no suitable flat areas and the summit is swept by unpredictable wind gusts.

A narrow footpath leads up the ridge immediately south of the south edge of the slide from the end of a four wheel drive road. Access to this road is from public roads leading to the northwest corner of the village of Hillcrest. The footpath can be seen from Hillcrest and is well known to local residents. Parts of the path are on rock and loose scree and appear unsuited to horses or trail bikes. The climb to Allan's Station 2, on the col between Third and South Peaks, is about 600 m and takes 2.5 h. It presents no problems to an experienced hill-walker who can expect to return in about an hour.

The west side of the summit of the mountain consists of bare rock slopes with angles from 35 to 55°. It is unsuited to conventional tripod-mounted surveying equipment.

Equipment had to be divisible into parts weighing less than 10 kg and capable of fitting into a backpack. There is no surface water on Turtle Mountain; water for drilling came from snow melted over a wood fire. Snowbanks persisted into July so no water had to be packed up the mountain.

2.3 INSTALLATION OF TM 71 GAUGES

Two TM 71 crack monitoring devices were installed immediately east of Station 2. The site was comparatively accessible; the fissure was sufficiently wide to accommodate the devices, and was talus filled providing a working floor. The rock mass on the fissure sides appeared sound at a depth of 1 m below the ground surface. Because this was a trial installation, designed, in part, to test the performance of TM 71 devices under the severe weather conditions on the mountain top, both instruments were installed in the same fissure within 3 m of one another.

The installation procedure for the TM 71 is described in Appendix 7.1. Weather conditions were adverse during the installation and minor modifications to the drilling equipment were necessary. Experience suggests that at an accessible site, three men could install a TM 71 within a day.

The instruments required careful handling: one grid was broken by the impact of a small stone during installation; another seems to have been disturbed during reading.

Readings taken with a flash and photo-sensitive paper are economical of materials but the image has a quality similar to blue line and does not reproduce. At the elevation of these installations, darkening of the sensitive paper is caused by cosmic radiation. A flash-equipped camera with self-developing film may give better image quality and permanence and still offer the convenience of checking the reading at the installation.

The readings of the instruments are tabulated in Appendix 7.2 and interpreted in Section 3.

2.4 TAPE EXTENSOMETER MEASUREMENTS

The remainder of the edges of Allan's wedge were to be instrumented with a less precise and more readily installed system. Eye-bolts were driven in the rock to form trilateral signs (Ter Stepanian 1980). The installation procedure is described in Appendix 7.3.

The installation ideally should be in hard rock distant from any fractures. Clearly, there should be some distance between the eye-bolts and the fissure as the rock around the fissure is often loose and highly fractured. These requirements restricted the choice of sites to nine, six of which form a continuous east-west belt running into Station 2. A map of the signs forms Figure 2.

Sign A does not conveniently fit on Figure 2. The coordinates of A are:

	Northing	Easting	Elevation (ft.)
A1	33449.44	33141.60	7101.61
A2	33490.63	33128.13	7095.39
A3	33478.13	33117.50	7092.99

Sufficient of the anchors are plotted on Stewart, Weir, Stewart, Watson, Heinrichs, and Dixon's map, (File No. 1-80-9514, 10551-123 St., Edmonton, Alberta) to allow the positioning of this figure on that map. Sites were not sought on Fissure 1 north of Sign A as the fissure was snow filled in early June 1980.

A model 518115 tape extensometer, manufactured by the Slope Indicator Company (3668 Albion Place N., Seattle, Washington, U.S.A., 98103), was selected to measure distances between the eye-bolts forming the trilateral signs. The accuracy of the measurements specified ($\pm$0.005 in. or 0.13 mm) is of the same order of magnitude as that promised by the TM 71. In the instrument, a steel engineering tape with holes punched at 2-in intervals is adjusted to a pre-set tension by a knurled collar whose rotation is recorded by a dial gauge reading to $\pm$0.001 in. Distance measurements are made by adding the dial gauge readings to the tape reading.

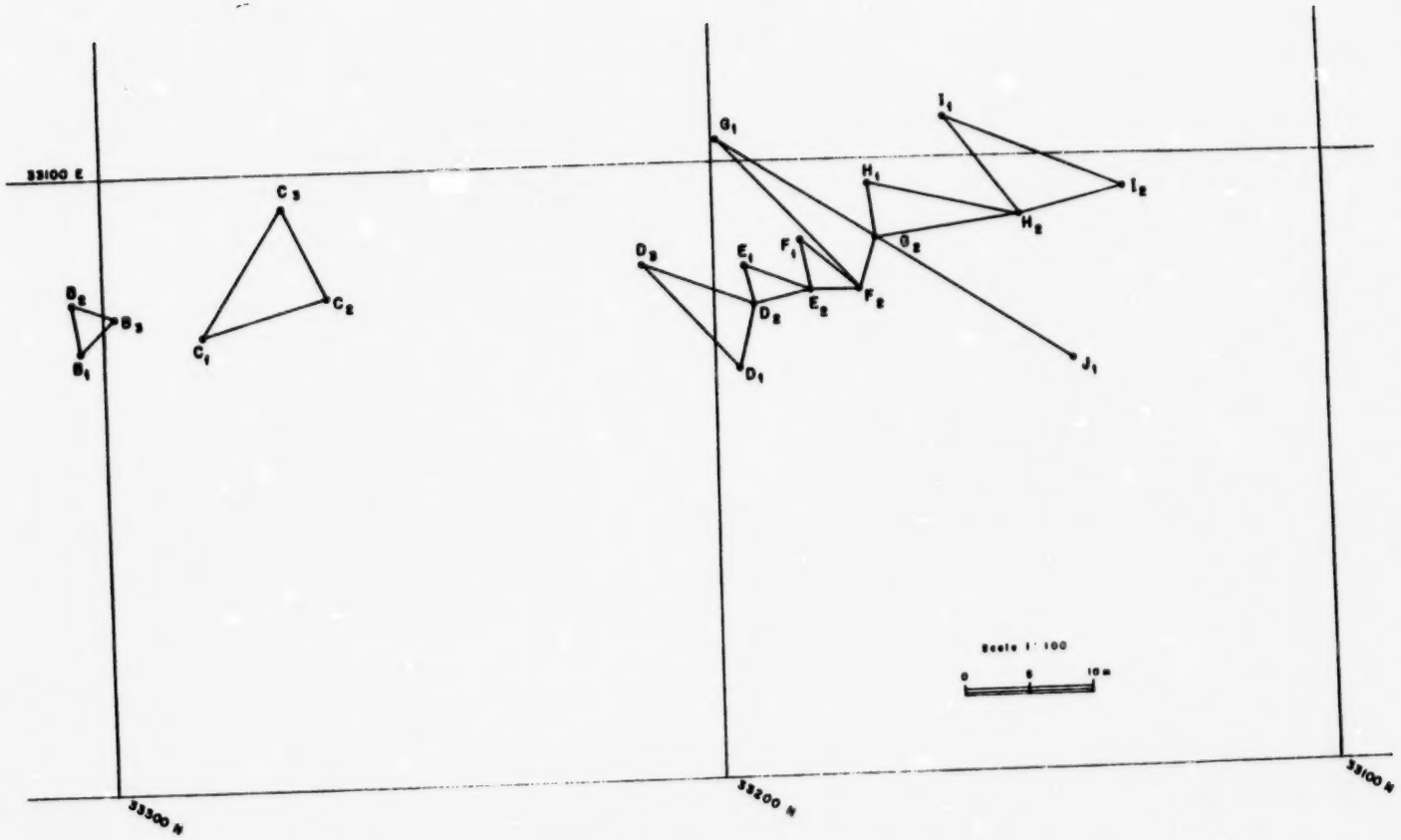

Figure 2. Trilateral signs on Turtle Mountain.

Two problems arose in operation: the tape dislodged from the pin penetrating the punched holes, and the pin holder unscrewed. The extensometer was modified after its trials in June by a pin through the pin holder and the addition of a snubbing device. Both of these modifications appeared to perform satisfactorily. Measurements made in June 1980, however, may be unreliable.

Most uses of the tape extensometer employ screw eyes installed so that the axis of the threaded portion of the eye is parallel to the long dimension or axis of the extensometer. Installations of this type are common in measurements of the convergence of tunnels and shafts. To place the eyes in this way would have required their installation on the walls of the crack itself. There, they would have been subject to the spalling that occurs from the crack walls and to the rain of debris into the crack as well as the exaggerated thermal effects that occur at the margins of blocks.

In avoiding these difficulties by driving the eyes into the rock surface at some distance from the crack, other problems are introduced:

1. Because the eye protrudes a maximum of only 3 cm above the rock surface, the extensometer may foul on the rock surface or the tape may touch the rock surface. Some contacts can be eliminated by chiselling the rock.
2. When the screw thread is at an angle to the tape, the thread is under a bending moment and the eye may also deform. It is not clear whether tensions in the tape are sufficient to cause permanent strain of the screw eyes or their anchorages.
3. The contact between the anchor and the fixed eye bolt on the tape extensometer is sometimes not free of torsion. The extensometer was generally placed to minimize the distance between the anchors but, in some cases, the optimum placing is not obvious and the previous contact position may not have been exactly reproduced.

As a result of these problems, the precision of the tape extensometer measurements does not meet that claimed under less adverse circumstances. A full discussion of the likely size of errors is presented in Section 3. Observations are tabulated in Appendix 7.4.

2.5 LEVELLING

Tape extensometer measurements allow the estimation of movements in the plane of the trilateral sign. For three dimensional movement vectors to be calculated, levelling was carried out around the network of signs. The results are included in Appendix 7.4 and their precision assessed in Section 3.

A rectangular plate, notched in its centre to accommodate the top of an eye-bolt, was fitted a central recessed bolt on which an automatic level could be screwed. The plate had bolts at each corner and a line level parallel to each side.

In operation, the level was screwed tight onto the plate by the central bolt and the plate was placed with the eye-bolt resting in the central notch. The corner screws of the plate were used to produce a coarse levelling of the instrument as shown by the line levels; the level screws produced a fine adjustment.

A special stadia rod was constructed by placing a steel tape down aluminum channel cut to 1 m lengths. Four of these lengths were hinged together forming a compact lightweight rod. The base of the rod accommodated a conical steel tip which fitted holes drilled in the tops of the eye-bolts. Thus, the rod could be replaced quite precisely on an eye-bolt.

Modifications to the design of the rod and the levelling plate were required after their June field trials. The locking devices on the hinges of the rod were initially too weak, the plate was too large, the coarse levelling screws were inconvenient, and the line levels were placed awkwardly. Levelling measurements taken in June have not been used in the data analysis.

3. INTERPRETATION OF DISPLACEMENT RECORDS

3.1 OBSERVATIONS

Examination of the tables in Appendix 7.2 shows there is a pattern in the movements in the x direction--horizontal, normal to the crack wall, and positive as the crack opens--which shows a maximum dilation towards the end of July and a closing of the crack in September (Tables 3 to 5, Appendix 7.2). The east vertical gauge showed about 0.1 mm closure; the east horizontal gauge showed a similar amount between 11:00, 29 July 1980 and 10:48, 23 September 1980. The west vertical gauge showed about 0.3 mm closure. The west horizontal gauge had been broken during installation in early June and was replaced on 23 September.

Measurements in the z direction--vertical and positive downwards--show approximately the same amount of movement but in opposite senses. This may reflect a toppling rotation about a horizontal axis outward from the east face of the mountain.

Westward movements along the y axis shown by the eastern unit, however, do not supporr the toppling hypothesis. Readings from the western horizontal gauge will be necessary to resolve this question. Total y movements are of the order of 0.1 mm, disregarding that believed due to disturbance on 23 September.

Repeated measurements at a constant temperature rarely show any change in fringe number unless the instrument has been disturbed. Disturbance may occur even when measurements are taken carefully: the gauges are sensitive to any small impact. Such an impact apparently occurred between the two measurements on the east horizontal gauge on 23 September.

The gauges are divided into 5 grad intervals and can be read to the nearest 5 grads. Again, the measurement is reproducible.

Assuming then that changes of 2 fringes or 5 grads in the axis of symmetry of a fringe can be reliably measured, movements of

the order of 0.05 mm at constant temperature are detectable. When the temperature changes rapidly within a day, the thermal correction of the measurements can be assessed free of any assumptions about the slow creep of the blocks. On 29 July, a change in temperature of 19°C over 4 h was corrected perfectly by the east vertical gauge. The east horizontal gauge was partially corrected and the west gauge showed little movement which the temperature correction reversed and exaggerated. It seems probable that differences in position and exposure of the gauges will make different corrections for each gauge appropriate. Further observations of performance under rapidly changing temperatures are necessary to come to any conclusions.

3.2 TRILATERAL SIGN DATA

The three eye-bolts in the rock constitute what Ter Stepanian (1980) has described as a simple trilateral sign. These signs may be analyzed graphically assuming that the distances, A1-A2, A2-A3, and A1-A3 are known and A1-A2 is fixed and unaffected by the movement V in the plane A1 A2 A3 (Figure 3).

The analysis proceeds by plotting A3 in its initial position and drawing through it lines parallel to A1-A3 and A2-A3. At some later time, the lengths A1-A3 and A2-A3 have increased (or decreased) by a1 and a2 and A3 has moved to A3'. A3' can be located by laying off the distances a1 and a2 along the axes +A1-A1 and +A2-A2 and dropping perpendiculars from a1 and a2 to intersect at A3' (Figure 4).

The analysis assumes A1-A3' = A1-a1 and A2-A3' = A2-a2. This approximation is good when the angles $\tan^{-1}$ (a1/A2-a2) and $\tan^{-1}$ (a2/A1-a1) are small.

The observations on the trilateral signs form Table 7 in Appendix 7.4. Most of the data within the Appendix are tape extensometer measurements, and diagrams similar to Figure 4 have been constructed for each sign with an origin located by the tape extensometer measurements of 30 July 1980.

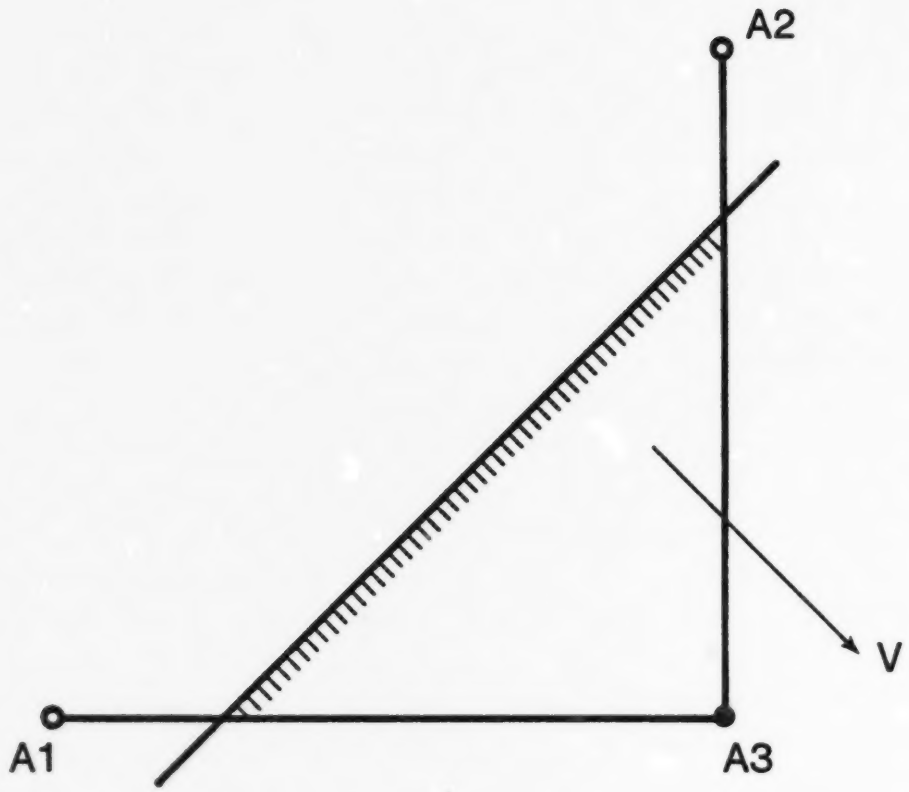

Figure 3. A trilateral sign.

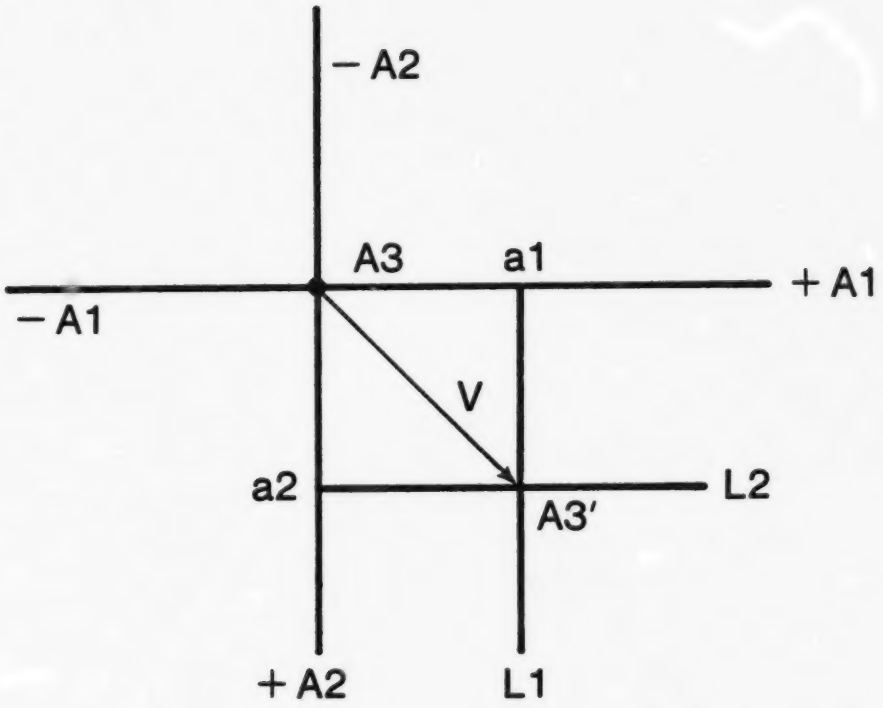

Figure 4. Geometry of a trilateral sign.

Table 2 shows the maximum departures within each sign from the 30 July data. They are of the order of 0.1 in (2.5)mm. Division by the length of the measurement leads to maximum strains within the signs of the order of hundreds of microstrains.

Closer examination of Table 2 indicates that signs A, B, and C have similar strains, substantially less than signs D to I, which lie across the east-west portion of the crack system rather than the north-south portion straddled by signs A, B, and C.

It may be that observations on the steep slopes where signs D to I are sited are more prone to error. However, C was a particularly awkward sign and errors there are low.

Errors might be broken down into those associated with the observation process and those correlated with the distance between the anchors and due to sag, imprecise thermal correction, and rock expansion. Notice in Table 2 that the larger strains in signs D to I are typically associated with shorter sign lengths. Such behaviour could be interpreted as indicating an important contribution from observation error. Alternatively, the behaviour would be consistent with a rigid translation of the rock wedge. These two models could be separated by careful observation of signs of different size on the same site.

A brief examination of a diagram like Figure 4, on which the dates of observations are also marked, is enough to give a subjective impression of trends in the successive changes in length in a particular sign. The chance of the three vectors formed by joining the four positions (on 29 July, 30 July, 19 August and 23 September) lying in the same quadrant, if errors are random, is 1 in 64. On this test, two of the nine signs showed some trend (Table 2). More data and a more sophisticated analysis are necessary before any claim to a pattern of movement can be made. Non-random movements are at present clearly less than 0.1 in (2.5 mm) over the 2-mo period.

Table 2. Abstract of Trilateral Sign Data.

Sign	Maximum difference from 30 July		Date	23 Sept.- 30 July	Random Changes?
	Inches	Microstrains			
A	+0.119	227	19 August	+0.019 +0.033	Yes
B	+0.025	215	23 September	-0.015 +0.025	No
C	+0.085	217	19 August	-0.001 -0.029	Yes
D	+0.159	497	19 August	+0.051 +0.009	No
E	+0.114	651	23 September	+0.058 +0.114	Yes
F	-0.133	779	29 July	+0.094 +0.011	Yes
G	+0.119	306	19 August	+0.039 +0.012	Yes
H	+0.104	835	23 September	+0.104 +0.026	Yes
I	+0.178	450	29 July	+0.010 +0.033	Yes

TM 71 gauges on the eastward extension of the crack monitored by Signs D to I show movements an order of magnitude less. The difference may be the filling of the crack under the TM 71's with talus, restraining motion across it. On the west slope, the crack is open to considerably greater depth. Notice, too, that the signs measure surface displacements whereas the TM 71's are monitoring movements of the blocks below ground surface.

The observations on 23 September provide the maximum temperature difference from those on 30 July. Except at B and C, all the signs show increase in length even after the appropriate corrections for the steel tape have been made. This can be interpreted as contraction of the rock wedge away from the crack during the period 30 July to 23 September. Signs B and C are shaded from the south and rock temperatures in their vicinity may be lower than air temperatures on 30 July, while the signs in direct sunlight probably have rock temperatures higher than air temperatures on 30 July.

Coefficients of expansion for rock are about $5 \times 10^{-6}/^{\circ}C$ (Larocque 1977: 118) so that the temperature change might be expected to produce about 50 microstrains over the sign length. This correction would improve the precision of the signs by about 20% but it should be supported by rock temperature measurements.

Other ways to improve the precision of the measurements include:

1. More systematic data collection procedures to eliminate gross errors in reading the instrument. Recording the observations on a form beside mean values of the distances would highlight any major changes allowing them to be checked on site.
2. Averaging multiple readings of the distances taken at constant bedrock temperature.
3. Devising a fixture to an eye-bolt which would eliminate torsion between the bolt and the fixed end of the extensometer.

3.3 LEVELLING

A look at the levelling data in Appendix 7.4 shows that a typical range in measurements made in July and August is 0.1 in (2.5 mm). The largest range is 0.182 in; the smallest agrees to the nearest thousandth of an inch. Early attempts at levelling with the prototype rod and plate in June have been discarded.

No obvious pattern exists in the errors. Temperature correction of the rod has not been attempted but appears likely to remove about 20% of the scatter in the data. The remaining errors may result from difficulties in keeping the rod exactly vertical (though it was fitted with a fish eye level), problems in exactly replacing the plate on the eye-bolt, and in re-erecting the rod. The observations were rounded to the nearest millimetre and seem to show scatter of the order of magnitude to be expected from random variation.

Changes of 5 mm would clearly indicate significant movements.

3.4 OTHER DISPLACEMENT RECORDS

There is a consensus in the rock mechanics literature that "slopes seldom fail without giving ample warning that they are about to do so" (Hoek and Bray 1977: 323). Cracks open in the crown of the potential slide and movement rates accelerate to failure. The acceleration is not generally smooth, but may be correlated with rainfalls or thaws which increase pore pressures in the moving mass. Conversely, dry weather or freezing may slow or terminate displacement.

When the geometry of the moving mass has been defined, monitoring moves to Level III (Larocque 1977) if the mass is not to be stabilized. Objectives in Level III are to plan measures to minimize disruption resulting from slope failure and to set a warning level at which these measures come into effect. The level must be sufficiently high to minimize false alarms, yet suffiently low to give ample warning of impending failure. What constitutes ample warning can only emerge from detailed contingency planning but a few days should be sufficient.

In what follows, the literature has been briefly reviewed to establish an order of magnitude for a warning level. This is intended as guidance in the design of a remote monitoring system.

Zavodni and Broadbent (1980) have reviewed the displacement records of 13 slides in open pit mines ranging in mass from 0.12 x 10^6T to 30 x 10^6T. Among their conclusions were (p. 73):

"2) It is unlikely that total failure collapse will take place within 24 hours if the displacement velocity is below 0.055 ft/day (17 mm/day) or within 48 hours if it is below 0.050 ft/day (15 mm/day).

3) A displacement rate above 0.17 ft/day indicates that a failure is probably in the progressive stage and that total collapse could occur with 0-48 days."

Calder and Blackwell (1980) report the monitoring of a slide along a gouge zone in a granodiorite at the Brenda Mine, Peachland, British Columbia. After meeting with union and B.C. Mines Department officials, mining proceeded on the understanding that movements of 0.5 in/d (12.5 mm/d) or 0.24 in/shift would stop operations in the failure area. During spring thaw, March 1979, movements of 1 in/d (25 mm/d) halted pit operations but did not lead to failure.

Brawner et al. (1975) described the monitoring of a failure in the highwall of Hogarth Pit, Steep Rock Mine, Atikokan, Ontario. Among the monitoring devices used were limit switches on wire extensometers which triggered alarms when movements of more than 0.5 in/d (12.5 mm/d) are recorded. These limits were exceeded when temperature drops of 30°C occurred in a few hours in January and the limit was increased to 1 in (25 mm). Failure occured the following June and was preceded by movement rates of as much as 12 in/d (300 mm/d).

The previous case histories indicate that movements of about 12 mm/d have been considered to give reasonable warnings of major slope movements. Discussions with a member of the Alberta Mines Inspectorate and management personnel at Alberta coal mines indicate that the limits they use are somewhat higher but of the same order of magnitude.

A warning system at Turtle Mountain then should be able to reliably detect and measure movements of 12 mm/d.

4. CONCLUSIONS

1. Allan's crack monitoring stations do not adequately cover the margins of the rock wedge whose fall he forecast.
2. Allan's crack monitoring stations can detect movements of about 30 mm normal to the crack margins. They are less sensitive to shear movements parallel to the crack margins.
3. TM 71 crack monitors can detect movements of about 0.1 mm. They are fragile and sensitive to disturbance. The two instruments which have been installed within a few metres of one another on the same crack were stable over the period of 11 June to 23 September 1980.
4. Trilateral signs formed by anchoring eye-bolts in the rock on either side of gaping cracks can detect movements of about 3 mm. Their precision can be enhanced. They have been installed in all accessible sites along the boundaries of Allan's wedge. No significant movements appear to have occurred in the period 20 July to 23 September 1980.
5. Levelling between the eye-bolts can detect movements of about 5 mm.
6. Case histories suggest that, at least a few days before any major rock slide or fall, movements of about 120 mm/d can be expected.

5. RECOMMENDATIONS

1. Monitoring of the network should continue over the next field season, June to September 1981, to see what effects winter has had.
2. A small mapping program based on an interpretation of the 1980 aerial photos should document joint and bedding orientations at the south end of the wedge. This information and an updated map of the cracks should allow kinematically feasible failure modes for the wedge to be determined.
3. If movements detected by the existing network do not substantially exceed those already recorded, the precision of the existing network should be improved by attempting to remove effects due to the thermal expansion of the rock.
4. If significant movements are recorded, the monitoring network should be expanded to include remote monitoring of movement by an electronic distance measuring device and crack movement gauges capable of remote interrogation. If no significant movements are recorded, a reconnaisance of sites for the EDM should be carried out with a review of suitable remote reading crack gauges.
5. If significant movements are detected, the appropriate authorities should be contacted to begin contingency planning for a slope failure. Contacts should be established with the Canadian Pacific Railways, the RCMP (who will control road traffic and road closures), the flood forecasting group of Alberta Environment, and the Municipality of Crowsnest (which might be expected to provide heavy equipment or explosives to construct a spillway across any natural dam which might form across the Crowsnest River).

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7. APPENDICES

7.1 INSTALLATION PROCEDURE FOR TM 71

7.1.1 Materials and Equipment

1. The TM 71 consists of (Figure 5):
   a) Two measuring units mounted on a frame;
   b) A (yellow) dummy for use in the mounting procedure; and
   c) A thermometer with magnetic attachment.

   These are all contained within a protecting hinged steel canister.
2. To complete the installation of the TM 71, it is necessary to:
   a) Prepare a pair of holders; and
   b) Seal the protective steel canister with a padlock.
3. Requirements for obtaining readings from TM 71 are:
   a) A roll of Kodak Linagraph Direct Print Paper (preferably the light weight paper but standard weight paper works); and
   b) A pocket flash unit modified to leave a 5 mm diameter aperture.

7.1.2 Preparation of the Holders

The hinge balls are tapered fittings at the ends of the TM 71. Demount them unscrewing their central screws and concave tapered washers.

The holders should be made of thick-walled (5 mm) steel tubes approximately 40 mm in diameter. These should be attached to the hinge balls by welding or by sweating on the hinge balls under elevated temperatures. For this reason, the inside of the ends of the tubes should be machined to match the hinge balls.

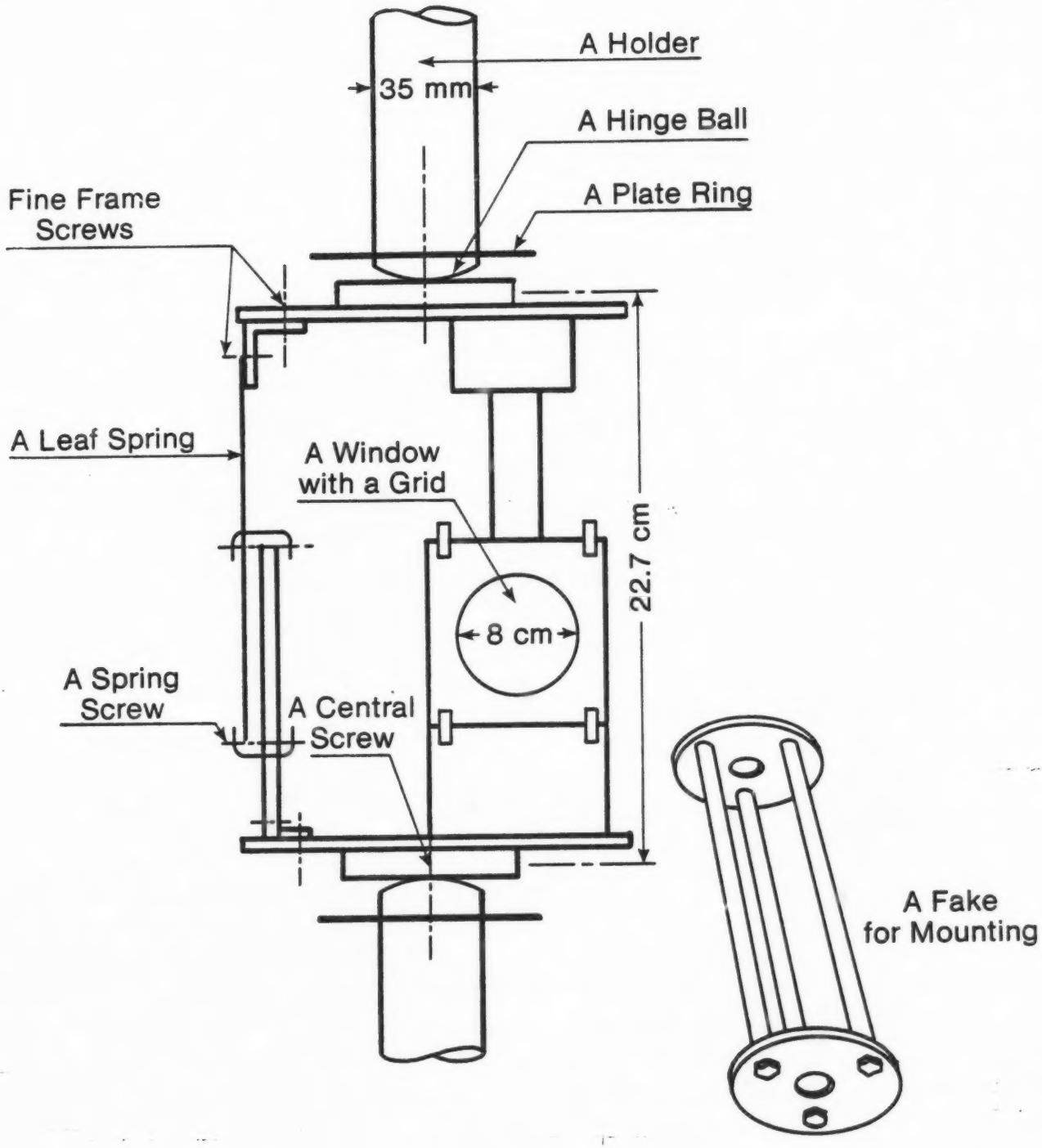

Figure 5. Sketch of TM 71, Crack Displacement Gauge

It is preferable to use straight holders but angular holders are acceptable, if necessary.

The length and shape of the holders will depend on the crack in rock to be investigated. The holders should be cemented into holes in the crack walls. The depth of the holes, in a range of 100 to 400 mm, will depend on the quality of the rock.

7.1.3 Selection of a Measuring Site

Preference should be given to:

1. Deep primary cracks and fractures separating huge, massive, representative blocks;
2. Covered, thermally isolated places like caves, shafts, galleries, and deep cracks;
3. The design specifications of the coring machine. Its size and operational range are important factors in site selection; and
4. The variable and peculiar nature of the rock surfaces or crack walls. They have a direct effect on the ability to anchor the coring machine properly. Although the surfaces of the cracks can be modified by chiselling, this slows the installation procedure, but may be necessary to accommodate the anchoring of the coring machine.

In view of these factors, an ideal site would be in a deep primary crack, separating massive blocks by about 50 cm. The crack surfaces should be of good quality rock, roughly parallel and planar.

7.1.4 Preparation of Holes for the Holders

Use an AX diamond core barrel bit to drill out holes 10 mm wider than the holder diameters (50 mm). It would be preferred that the holes would enable bridging of the gap in one straight and horizontal line, although this is not necessary.

The drill shown in Figure 6 was quite effective, though difficulties arose due to limited work space. Some mechanism should be installed on the core barrel for removing it from its hole.

7.1.5 Mounting the Instrument

Attach the dummy to the holders by inserting the central screws without the spherical washers in the hinge balls at the ends of the holders. Cement the holders into the prepared holes using good quality, quick-setting mortar. Fill the seam well and let it set overnight. Temperature and humidity will have an effect on the setting time of the mortar. Take this into account when selecting the mortar. (The Turtle Mountain installation used WILL-KWIK-SET, mixing one part material to one part water by weight.)

Release the holders by demounting the dummy, and replace it with the TM 71. Time can be saved by having the TM 71 adjusted to the length of the dummy beforehand. Clear all loose rock away from the installation area to prevent falls onto the instrument.

1. First put the thin plate rings on the holders.
2. Wet the hinge balls and the central screws with several drops of epoxy resin or another similar cement to prevent involuntary movements.
3. Catch the instrument loosely in between the holders using the central screws with the spherical washers. To get the instrument into place, one of the four screws on both side plates of the instrument must be removed temporarily.
4. Release alternately the three yellow connection bars while tightening the central screws until the instrument is joined rigidly to the holders in the desired position. A normal position is one measuring unit horizonta, the other one vertical.

Figure 6. Drilling equipment for TM 71 installation.

5. Remove the connection bars completely and tighten the central screws.
6. Fix the grids in a good contact and then in zero positions using the fine frame screws. Check the zero positions by the darkening of targets in the glass windows. Work without force. Be sure that all screws are tightened eventually. It may be difficult to fix an exact dark zero fringe pattern. This is not necessary, and zero can be found mathematically. In case of larger movements the direction of which is undoubted, the original position of grids can be set in the extreme opposite direction to increase the range of measurements. In any case, the original fringe pattern is to be recorded together with the temperature.
7. Loosen the spring screws which hole the grid glasses in contact and fix them again in a position which ensures a full but light contact. A good contact is shown by clear and sharp fringe patterns which are symmetrical along the axis of a displacement.
8. Attach the magnetic thermometer to one of the central screws.
9. Check the instrument by sharply knocking a holder. The target meter should react by showing fringe patterns which return again to a constant original position. Very long holders may show narrow dispersion of patterns which can be eliminated by loosening spring connections. For clear observation of fringes put a piece of white paper at a distance behind the window.
10. Put the protective canister on. The thin plate rings are to be inside the canister. They provide protection against unbolting of the instrument.

11. Take readings of fringes and temperature.
12. Close up the canister and padlock it.

7.1.6 Recording the Installation

1. Make a sketch of the installation with the orientation of axes and dimensions:

   +x ... grid centre to 0^g

   +y ... horizontal grid centre to 100^g

   +z ... vertical grid centre to 100^g

Usually, the instruments are oriented so the +x axis points downslope.

2. Record exactly the components x_t, y_t, z_t of the distance between the points where the holders are stuck into the rock. The components have to be oriented in accordance with the x, y, z system, the distance vector oriented so that x_t is positive. The components serve for temperature corrections.

3. Take initial readings.

7.1.7 Reading the Instrument

Kodak Linagraph Direct Print Paper cut to 60 x 60 mm pieces is required.

Procedure:

1. Press the paper lightly behind the glass and flash through the window from a distance of about 200 to 400 mm. (This distance will be determined by previous experiments using the equipment to maximize the quality of the results.) A 60 mm x 60 mm piece of galvanized sheet metal is helpful as backing for the paper. Keep the paper flush with the glass for consistent exposure and impression throughout the print.
2. Write down on the back side of the picture: place, date, time, temperature, and horizontal or vertical grid.

3. Expose the picture to diffuse light in a shaded area, perhaps under a blanket to shield it from direct contact with sun's rays. Exposure to direct sunlight may result in loss of the grid image. Direct reading by eye is possible but the assessment of the pattern may suffer a minor error.

7.1.8 Frequency of Readings

The frequency of readings is a compromise between an incentive to know the displacements in detail, including those due to temperature changes, and an ability to get to a remote measuring site. A reading every second month is usually satisfactory even in surface cracks with considerable temperature oscillations.

A full year of observation is recommended, if possible, to obtain a complete annual picture of dilatations interfering with gravitational movements. However, displacement rates of more than 1 mm/y can be established without a full year observations.

7.1.9 Interpreting the Fringe Patterns

A Moire fringe pattern should be a perfectly symmetrical picture of interference fringes. It is defined by an oriented axis of symmetry and a number of fringes.

1. Find the symmetry axis, which is passing through the thinnest regions of the pattern. The other axis of symmetry is perpendicular passing through the densest regions. This axis is identical to the sharpest fringe of the pattern.
2. Read orientation (a) of the axis at the angular scale in the direction marked by a continuous arched slit along the scale. The opposite orientation would show only separate marks of the scale.
3. Count the number (N) of fringes at one side of the symmetry axis, which defines orientation. The number

N, is related to dark fringes when looking directly at the window. In a print which is negative, white fringes should be detected. The number $N > 0$ is odd regarding symmetry. In the case of a fringe laying just on the orientation axis, counting one-half at each side results in an even number N. Total darkening of the window grid means $N = 0$ and the orientation is then indeterminate.

7.1.10 Calculating Displacements

1. Find a_h, N_h; a_v, N_v for both horizontal h and vertical v patterns.
2. Calculate displacements:

$$x_h = 0.5\ e.N_h \cos a_h;\ x_v = 0.5\ e.N_v.\cos a_v$$

$$y = 0.5\ e.N_h \cos a_h;\ z = 0.5\ e.N_v.\sin a_v$$

The values $x_h = x_v$, y, z are components of the investigated displacement vector $\vec{u}$ in space. The components are measured in coordinates defined by grid orientations relative to the zero original position of grids, which is assumed. If the original position of grids were not zero, true displacement components should be found by subtracting fictious original displacements given by the original set of readings N_{ho}, a_{ho}, a_{vo}. The displacement vector includes thermal reaction of the instrument and the holders. A correction is regularly calculated using x_t, y_t, z_t; the thermal reaction coefficient being $\alpha_t = 12.10^{-6}/^{o}C$. The constant e for the respective instruments: e = 1/15 mm.

Acknowledgments

This section is based on a document provided by:

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7.2 TM 71 OBSERVATIONS

7.2.1 Explanation of Tables 3 to 6

x_t, y_t, and z_t are the components of the lengths of the steel supporting holders in the coordinate system of the instruments. The holders were installed horizontally.

Temp. is the temperature at the time of measurement in degrees Celsius.

Time is the time of measurement to the nearest minute on a 24-hour clock.

Data consists of two numbers for the day of the month, two for the month in the year, and two for the year in the 20th century.

a is the orientation of the axis of symmetry in the Moire fringe pattern given in grads.

N is the number of fringes on one side of the symmetry axis.

x_v, x_h are the values of the x component of the displacement vector $\vec{u}$ measured on the vertical and horizontal grids respectively of the instrument.

Table 3. Displacements Measured in the Vertical Plane by the Eastern TM 71 Unit.

Temp	Time	Date	x_t, 406.4 mm, y_t, 0, z_t, 0 a	N	x_v	$(T-10)x_t$	$x_v - x_t$	z
10	1500	10/06/80	310	1	0.01	0.00	0.01	-0.03
10	1030	11/06/80	000	3	0.1	0.00	0.1	0.00
21	1525	05/07/80	380	1	0.03	-0.045	0.075	-0.01
7	1100	29/07/80	050	3	0.07	0.02	0.05	0.07
26	1530	29/07/80	110	3	-0.02	-0.07	0.05	0.10
15	1030	30/07/80	085	5	0.04	-0.02	0.06	0.16
11	1055	19/08/80	125	5	-0.04	0.00	-0.04	0.16
4	1100	23/09/80	110	7	-0.04	0.02	-0.06	0.23

Table 4. Displacements Measured in the Horizontal Plane by the Eastern TM 71 Unit.

			x_t, 406.4 mm, y_t, 0, z_t, 0					
Temp	Time	Date	a	N	x_h	$(T-10)x_t$	x_h-x_t	y
10	1500	10/06/80	335	1	0.02	0.00	0.02	-0.03
10	1030	11/06/80	350	3	0.07	0.00	0.07	-0.07
21	1527	05/07/80	280	7	-0.07	-0.045	-0.025	-0.02
7	1100	29/07/80	290	7	-0.04	0.02	-0.02	-0.23
26	1530	29/07/80	260	9	-0.18	-0.07	-0.11	-0.24
15	1030	30/07/80	280	8	-0.08	-0.02	-0.06	-0.25
11	1045	19/08/80	275	11	-0.14	0.00	-0.14	-0.34
4	1048	23/09/80	280	13	-0.13	0.02	-0.15	-0.41
4	1057	23/09/80	295	55	-0.144	0.02	-0.164	-1.827

Table 5. Displacements Measured in the Vertical Plane by the Western TM 7. Unit.

			x_t, 506.4 mm, y_t, 0, z_t, 0					
Temp	Time	Date	a	N	x_v	$(T-10)x_t$	x_v-x_t	z
10	1400	11/06/80	340	3	0.06	0.00	0.06	-0.08
19	1535	05/07/80	350	9	0.21	-0.05	0.2	-0.21
8	1100	29/07/80	355	9	0.23	0.02	0.21	-0.19
26	1530	29/07/80	350	9	0.21	-0.09	0.30	-0.21
15	1030	30/07/80	350	7	0.17	-0.02	0.19	-0.17
23	1430	30/07/80	360	9	0.24	-0.07	0.31	-0.18
12	1110	19/08/80	330	9	0.14	-0.02	0.16	-0.27
5	1140	23/09/80	315	8	0.06	0.04	0.02	-0.26
6	1240	23/09/80	310	9	0.05	0.02	0.03	-0.30

Table 6. Measurement in the Horizontal Plane by the Western TM 71 Unit.

			x_t, 506.4 mm, y_t, 0, z_t, 0					
Temp	Time	Date	a	N	x_h	$(T-10)x_t$	x_h-x_t	y
6	1235	23/09/80	110	15				

(T-10) x_t is the thermal correction to x_v and x_h where T is the temperature in degrees Celsius and correction is to a standard value of $10^{o}C$.

y, z are the values of the y and z components of the displacement vector $\vec{u}$ measured on the instrument grids.

All lengths are measured in millimetres.

7.3 INSTALLATION PROCEDURES FOR ROCK ANCHORS

The screw eyes fit the thread of Phillips Red Head Flush Anchors--0.25 in bolt size (Catalogue Number F-14, Phillips Drill Company, Michingan City, Indiana, 46360, U.S.A.). The anchors were driven into the rock by a hammer striking a Hand Driver which screws into the anchor. Phillips manufactures the FH-300 series of holders but other Hand Drivers of 0.25 in anchors are useable. Replacement of the threaded ends of the Hand Drivers is occasionally necessary.

The installation procedure is:

1. Clear loose dirt from anchor site to expose rock.
2. Screw the 0.25 in anchor onto Hand Driver, ensuring a match with the tightened nut on the end of the hand driver by inserting a washer between the anchor and the nut.
3. Drive the anchor by light rapid blows on the Hand Driver, rotating the Driver a quarter turn or so between blows. After every five blows, the rock dust should be dislodged from the anchor teeth by lightly tapping the anchor. Dust should also be blown out of the anchor hole by inserting a length of plastic tubing into the hole and blowing.
4. When the anchor hole is driven to the full 1.25 in depth of the anchor, carefully clean out the hole and the anchor tip and insert the steel expander plug in the anchor tip. Replace the anchor in the hole and set it by driving the anchor until it is flush with the rock surface.
5. Screw in the screw eye as far as it will go. Prevent water and frost penetration along the thread and around the outside of the anchor by applying a generous coating of epoxy cement. Scotch-Weld Structural Adhexive (3M Company, 3M Center, St. Paul, Minnesota, 55101)

has proved suitable for this purpose. Setting time of this adhesive depends on the temperature, below about 15°C it may be as much as 12 h, and screw eyes should be left overnight before measurements are made.

7.4 TRILATERAL SIGN OBSERVATIONS

Temperature is in degress Celsius.

Lengths are measured in inches.

Angles are measured in degrees and indicated by M.

Angles computed from the lengths of sides are indicated by C.

Elevation differences include the instrument constant, 4 in for the Sokkisha C3A, and the plate thickness, 1.567 in.

Readings believed to be an inch in error have the correct reading placed underneath in brackets.

Corrected lengths are compensated only for changes in the steel surveying tape. The reference temperature is 10°C.

Table 7. Trilateral sign observations.

A

Date	June 10	June 11	1/ July 29	2/ July 29	July 30	1/August 19	2/ August 19	Sept. 23
Temp.	18.0	12 5	7.0	16.0	13.0	5.9	7.7	2.0
A1-A2	523.524	523.774	523.758	523.627	523.665	523.716	523.717	523.752
Corrected	523.573	523.789	523.740	523.663	523.683	523.691	523.703	523.702
Temp.	18.0	13.8	7.0	16.0	12.0	5.8	7.7	2.0
A1-A3	470.437	470.565	470.627	470.577	470.542	470.695	470.603	470.631
Corrected	470.481	470.586	470.611	470.610	470.553	470.672	470.590	470.586
ELEVATION (inches)								
A1-A2	71.102		69.134		69.055	69.213		
A1-A3	107.145		97.933		97.795	97.992		
A2-A3	36.043		28.799		28.74	28.760		
A2 A1 A3			M21.33		M20.15		M21.15	

continued ...

Table 7. Continued.

B

Date	1/ June 10	2/ June 10	June 11	1/ July 29	2/ July 29	July 30	1/ August 19	2/ August 19	Sept 23
Temp.	15.0	22.5		7.0	17.0	13.0	6.1	7.7	1.0
B1-B2	162.638	162.084		162.801	162.774	162.784	162.775	162.782	162.793
Corrected	162.647	162.108		162.795	162.787	162.790	162.768	162.778	162.775
Temp.	15.0	22.5	10.4	7.0	17.0	12.0	6.1	7.0	2.0
B1-B3	116.028	116.312	116.322	116.302	116.284	116.282	116.287	116.298	116.321
Corrected	116.035	116.329	116.323	116.298	116.293	116.285	116.282	116.294	116.310
Temp.		22.5	10.6			12.0	6.3	7.4	1.0
B2-B3		96.923	97.092			96.875	96.908	96.882	96.918
Corrected		96.937	97.093			96.877	96.904	96.879	96.908
ELEVATION									
B1-B2				133.403		133.403	133.386		
B1-B3				63.146		63.13	63.110		
B2-B3				70.26		70.216	70.276		
B2 B1 B3						C41.895		C41.882	C41.895

continued ...

Table 7. Continued.

C

Date	1/ June 10	2/ June 10	1/ July 29	2/ July 29	July 30	1/August 19	2/ August 19	Sept 23
Temp.	24.0	13.0	11.0	13.0	12.0	5.9	6.9	2.0
d3-C1	390.859	391.067	391.099	391.011	391.078	391.191	391.065	391.124
Corrected	390.923	391.081	391.104	391.025	391.087	391.172	391.051	391.086
Temp.		13.0	12.0	13.0	11.0	5.8	6.2	2.0
C3-C2		236.764	236.779	236.696	236.764	236.756	236.755	236.761
Corrected		236.772	236.789	236.704	236.767	236.744	236.745	236.738
ELEVATION								
C3-C1								
C3-C2			247.539		247.460	247.598		
C2-C1			123.779		123.779	123.760		
			123.760		123.681	123.838		
C2 C3 C1								
					C47.911			

continued ...

Table 7. Continued.

D (The original installation of D_3 was destroyed by a small rockslide)

Date	July 29	July 30	1/ August 19	2/ August 19	Sept. 23
Temp.	20.0	11.5	5.7	6.3	2.0
D1-D3	319.661	319.683	319.724	319.860	319.769
Corrected	319.698	319.687	319.708	319.846	319.738
Temp.	19.0	11.0	5.5	7.8	2.0
D3-D2	219.315	219.336	219.346	219.337	219.369
Corrected	219.338	219.339	219.335	219.331	219.348
Temp.		12.0	6.2	7.0	2.0
D2-D1		209.803	209.820	209.807	209.843
Corrected		209.808	209.811	209.800	209.823
ELEVATIONS					
D1-D3		132.382	132.480		
D3-D2		31.860	31.791		
D2-D1		164.188	164.271		
D1 D3 D2			C26.197	C26 176	C26.141

continued ...

Table 7. Continued.

E

Date	June 10	1/ July 29	2/ July 29	July 30	1/August 19	2/ August 19	Sept. 23
Temp.	13.5	14.0	15.0	12.0	5.4	7.3	3.0
E1-E2	175.145	175.231	175.184	175.164	175.203	175.206	175.241
Corrected	175.152	175.239	175.194	175.168	175.194	175.201	175.226
Temp.	17.0	15.0	16.0	11.0	5.4		3.0
E1-D2	102.713	102.616	102.563	102.581	101.608		102.705
Corrected	102.721	102.622	102.570	102.582	101.603		102.696
					(102.603)		
Temp.				12.0			
E2-D2				200.651			
Corrected				200.656			
ELEVATIONS							
E1-E2				94.655	94.764		
E1-D2		69.567		69.493	69.567		
E2-D2				164.148	164.330		
E2 E1 D2				C54.429			

continued ...

Table 7. Continued.

F

Date	June 10	1/ July 29	2/ July 29	July 30	1/August 19	2/ August 19	Sept. 23
Temp.	16.5	21.0	16.0	12.0	5.4	7.0	2.0
F1-F2	170.869	170.899	170.785	170.786	170.891	170.774	170.900
Corrected	170.882	170.921	170.797	170.790	170.882	170.768	170.884
Temp.	14.5	16.0	16.0	12.0	5.2	7.3	2.0
F1-E2	118.505	118.577	119.435	119.449	118.470	118.453	118.474
Corrected	118.511	118.585	119.443	119.452	118.463	118.449	118.463
			(118.443)	(118.452)			
ELEVATIONS							
F1-F2		46.535		46.594			
F1-E2		59.331		59.227			
F2-E2		105.866		105.821			
F2 F1 E2		M42.830		M40.417			

continued ...

Table 7. Continued.

G

Date	June 10	1/ July 29	2/ July 29	July 30	1/August 19	2/ August 19	Sept. 23
Temp.	22.5	13.0	18.0	13.0		6.9	2.0
G1-F2	427.100	427.032	427.021	427.038		427.048	427.133
Corrected	427.162	427.047	427.061	427.053		427.033	427.092
Temp.	22.5	17.0	18.0	13.0	6.0	6.8	2.0
G1-G2	389.236	389.236	389.178	389.175	389.326	389.253	389.238
Corrected	389.292	389.268	389.214	389.189	389.308	389.239	389.201
ELEVATIONS							
G1-F2				69.148			
G1-G2		.000		.006			
F2-G2		68.799		68.912			
G2 G1 F2				16.382			

continued ...

Table 7. Continued.

H

Date	June 10	1/ July 29	2/ July 29	July 30	1/August 19	2/ August 19	Sept. 23
Temp.	23.0	16.0	17.0	14.0	4.4	6.9	2.0
H1-G2	124.441	124.448	124.448	124.473	123.478	124.439	124.595
Corrected	124.460	124.457	124.458	124.479	123.470 (124.470)	124.435	124.583
Temp.	25.5	16.0	17.0	14.0		7.8	2.0
H1-H2	312.295	312.396	312.300	312.301		312.346	312.372
Corrected	312.351	312.418	312.325	312.316		312.338	312.342
ELEVATIONS							
H1-G2				55.246	55.216		
H1-H2		48.898		48.966	48.996		
H2-G2				104.212	104.212		
H2 H1 G2				M22.75		M23.25	

continued ...

Table 7. Continued.

Date	June 10	1/ July 29	2/ July 29	July 30	1/August 19	2/ August 19	Sept. 23
Temp.		16.0	16.0	14.0	4.0	7.9	2.0
I1-H2	263.569	262.814	263.699	263.699	262.737	263.823	263.746
Corrected		262.832	263.717	263.711	262.719	263.817	263.721
		(263.832)			(263.719)		
Temp.	24.5	16.0	17.0	13.0	4.8	7.6	3.0
I1-I2	395.101	395.101	395.101	395.293	395.355	395.373	395.374
Corrected	395.168	395.129	395.133	395.307	395.331	395.362	395.341
ELEVATIONS							
I1-H2		74.567		74.567	74.488		
I1-I2		36.181		36.181	36.358		
I2-H2		110.748		110.748	110.846		
I2 I1 H2		M32.75		M32.18		M34.25	

continued ...

Table 7. Concluded.

J

Date	June 10	1/ July 29	2/ July 29	July 30	1/ August 19	2/ August 19	Sept. 23
Temp.	22.5	16.0	16.0	14.0	4.0	7.4	2.0
G2-J1	473.095	473.100	473.183	473.053	473.177	473.126	473.181
Corrected	473.164	473.133	473.216	473.075	473.144	473.112	473.136
ELEVATION G2-J1		30.866		25.600	25.669		

POOR

QUALITY

ORIGINAL